Spin Torque and Nanorings

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Many phenomena have been discovered and applied in suitable magnetic nanostructures, in which the effects of spin currents, the interplay of materials, and the geometry of the entities are important features. In this presentation, some new aspects of spin torque and arrays of magnetic nanorings will be described.

Spin Torque: A new magnetoelectronic effect, the spin torque (ST) effect, has recently been discovered that reveals novel physics as well as potential device applications. The basic physics of the ST effect is that a spin-polarized current carries an angular momentum, which is proportional to its spin polarization and current density. At a sufficiently high current density, the large angular momentum of a spin-polarized current can exert a torque on a FM entity to switch its magnetization or to stimulate spin precession (spin waves).

The simplest geometry for realizing the ST effect is a trilayer (e.g., Co/Cu/Co) that exhibits GMR. In GMR, the electrical resistance is altered when a magnetic field changes the magnetic configuration of the trilayer. The ST effect is the inverse effect, in which an electrical current alters the magnetic configuration without a magnetic field. The consequence of the transferred torque depends on the *polarity* of the current, favoring parallel alignment in one polarity and antiparallel alignment in the opposite polarity.

We have recently demonstrated current-driven switching using point contact on a *continuous* Co/Cu/Co trilayer instead of lithographically produced nanopillars[1]. We show that the critical current density and critical voltage for switching nanodomains are uniquely defined and independent of the contact resistance. Switching at room temperature has also been accomplished thereby demonstrating magnetic recording via a spin-polarized current without using a magnetic field.

We have recently also observed a new type of ST effect occurring in a *single* ferromagnetic (Co) layer, which does *not* exhibit GMR[2]. This new form of ST effect is the *inverse* effect of *domain wall magneto-resistance* (DMR). Previously, as suggested by theories and interpreted as such by experiments, switching at low fields and spin precession at high fields are two aspects of the ST effects in a magnetic field. Our data in a single Co layer shows conclusively that the experimental signatures commonly taken as evidences for spin precession are in fact those of switching under a large magnetic field of up to 9 T. A spin current can readily overcome the effect of any realistic magnetic fields.

Arrays of Magnetic Nanorings: Much attention has been focused on small magnetic entities of various geometrical shapes. Magnetic entities below 5 μm in sizes are usually made by e-beam lithography in small quantities. One often needs to resort to surface MOKE, MFM, and Hall bar to measure them. Magnetic nanorings, despite their special attributes, are particularly challenging for e-beam lithography in which each nanoring is lithographically defined by two accurately positioned concentric radii.

We have recently developed a new method of using self-assembly of two-dimensional nanoparticle arrays as templates for the fabrication of a large number (10^9)

of small nanoring (100 nm in diameter) over a macroscopic area (5 cm x 5 cm) with a high areal density (45 rings/μm^2). Furthermore, these nanorings can be made of a wide variety of materials, either single materials or multilayers. With the success of this new method, we can now address a host of interesting problems capitalizing on the unique nanoring geometry.

The large number of nanorings that we have produced permits full magnetic characterization using magnetometry. We have studied the various states (onion state, vortex states, twisted states, etc.) that are unique to nanorings and compared them with those of micromagnetcis simulations. Finally, since each magnetic nanoring can acquire one of two chiralities of the vortex state, one can exploit nanorings in magnetic storage as in the proposed vertical magnetic random access memory (VMRAM).

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[1] *T. Y. Chen, Y. Ji, and C. L. Chien, Appl. Phys. Lett.* ***84****, 380 (2004).*

[2] *T. Y. Chen, Y. Ji, C. L. Chien, and M. D. Stiles, Phys. Rev. Lett.,* ***93****, 026601 (2004).*